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Validation of MODIS Aerosol Optical Depth Retrieval with AERONET Data

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Abstract—*Satellite derived column aerosol optical depth (AOD) is a cost effective way to monitor and study aerosols distribution and effects over a long time period. The aerosol optical depth (AOD) product can be used to provide an estimate of air quality over the land surface. It is regularly derived from and MODIS (Moderate Resolution Imaging Spectroradiometer) sensor and used by the scientific community in various climatic studies. In the present study an attempt has been made to retrieve AOD measurements from MODIS and a comparison has been carried out using AErosol RObotic NETwork (AERONET) data over Delhi, using time-series of MODIS surface reflectance products. Aerosol optical depths (a) were derived operationally from the MODIS and skyradiometer measurements at 500 nm wavelength. The results show that the MODIS retrieved aerosol optical depth is in good agreement with that of retrieved from AERONET. The RMSE are found to be ±0.0295 and MODIS sensor retrieved aerosol optical depth is closer to Skyradiometer (correlation = 0.95, slope = 0.936 and intercept = +0.023). With this validation we believe that MODIS aerosol products can be used quantitatively in many applications with caution for possible residual clouds, snow/ice, and water contamination.*

Keywords: *Aerosol Optical Depth, Skyradiometer, Climatic Studies*

1. INTRODUCTION

Aerosols are one of those important geophysical parameters that determine the earth's energy balance and hydrological cycle. These Suspended airborne particles scatter solar radiation back, absorb solar radiation in the atmosphere, and shade the earth's surface. Light can be scattered to the sensor through single back scattering by an aerosol particle or by a series of forward and/or backward scattering events in the atmosphere. Absorption by aerosol particles is generally spectrally and angularly dependent.

Aerosol Optical Depth (AOD) is one of the most important key parameters which can not only reflect the characterization of atmospheric turbidity[1], but also identify the climate effects of aerosols [1,2]. It is defined as the attenuation of direct solar radiation passing through the atmosphere by scattering (angular redistribution of energy) and absorption (conversion of energy into either heat or photochemical change) due to aerosols. Monitoring AOD at different wavelengths is useful for deriving additional information on the size distribution of particles, as well as the study of its variation with season, which in turn helps to identify the variation in the source strength of different particles emitted into atmosphere. Extensive measurements of turbidity parameters have been carried out in the past at different Indian stations using single- and three-wavelength Volz sun photometers [3].

Use of satellite observations is the most efficient way to determine aerosol physical properties on the temporal and spatial scales needed to understand and monitor their effects on the earth–atmospheric system[4]. Traditional aerosol satellite-based retrievals have been limited to ocean areas that are dark in the visible and near IR [5]. For land areas, the surface contribution to the reflected visible and near-IR is significantly larger than contributed by aerosols. Therefore, aerosol characterization over land with visible and near-IR observations is very difficult without a precise characterization of the surface radiative properties. As a way of acquiring AOD, satellite remote sensing retrieval has many advantages comparing with the traditional detection, such as wide area coverage, fast accessing cycle, lower cost, etc.

The MODIS (Moderate Resolution Imaging Spectroradiometer) onboard EOS Terra (10:30 a.m., equatorial crossing) and Aqua (1:30 p.m., equatorial crossing) satellites launched in 1999 and 2002, respectively, having seven calibrated spectral channels in the wavelength range 470–2100 nm with spatial resolution in the range 250–500 m has initiated a new era in aerosol remote sensing [6,7]. This satellite pair continuously monitors aerosols over the ocean and land with nearly full global coverage on a daily basis [8]. Aerosol parameters provided by MODIS include spectral AOD (at wavelengths 470, 550 and 660 nm over land and at wavelengths 470, 550, 660, 865, 1200, 1600 and 2100 nm over ocean), angstrom exponent (one value over land generated using wavelengths 470 and 660 nm and two values over the ocean, one generated using 550 and 865 nm in the short wavelength range and the other using 865 and 2100 nm in the long wavelength range) [9].

2. AERONET

The AERONET (**AE**rosol **RO**botic **NET**work) is a global consortium of ground based sun-sky radiometers where data is centrally archived. A sun photometer is an instrument which measures the intensity of the Sun's light, when pointed directly at the Sun. Any aerosols and gases (haze) between the Sun and the photometer tend to decrease the Sun's intensity. A hazy sky would read a lower intensity of sunlight and give a lower voltage reading on the photometer. A clear blue sky would result in a greater intensity and a higher voltage reading. The goal of this site is to assess aerosol optical properties and validate satellite retrievals of aerosol optical properties. The network imposes standardization of instruments, calibration, and processing. Data from this collaboration provides globally distributed observations of spectral AODs, inversion products, and precipitable water in geographically diverse aerosol regimes. AERONET data is available in 340 nm, 380 nm, 440 nm, 500 nm, 670 nm, 870 nm and 1020 nm. Three levels of data are available from this website: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (Cloud-screened and quality-assured) [10]. Only Level 1.5 cloud screened data was used since calibrated Level 2.0 data were not available for the study sites at the time of analysis.

Fig. 1: A view of the skyradiometer and site in Delhi

The main objective of this study was to compare the MODIS retrieved spectral AODs on-board Terra and Aqua, and temporally coincident measurements of ground truth data obtained from AERONET (Aerosol Robotic Network) solar direct radiance measurements. The purpose of validation was to detect biases, if any, originating from the processes involved in deriving the products and to establish the accuracy levels of the products, based on comparison with the independent observations of known accuracy(ground truth). The datasets were collocated from operational AERONET site in Delhi-28°35′ N, 77° 12′ E, 216 m and compared with AODs retrieved from MODIS bi-products. The sun photometers from ground sites provide unprecendent spectral coverage from visible(VIS) to solar near-Infrared(NIR) and infrared(IR) wavelenghts. Aerosol optical depths (a) were derived operationally from MODIS (Moderate Resolution Imaging Spectroradiometer) measurements over location at 500nm wavelength.

3. VALIDATION APPROACH

In order to take into account both spatial and temporal variabilities of aerosol distribution, the MODIS retrievals at 10 km×10km resolution and the AERONET direct Sun mesurements at 15 minute interval need to be co-located in space and time. At least 2 out of possible 5 AERONET measurements within ±30 min of MODIS overpass and at least 5 out of possible 25 MODIS retrievels in a square box of 50km×50km centered over AERONET site were required. The mean values of co-located spatial and temporal ensemble were used in linear regression analysis and in calculating RMS errors.

4. RESULT AND DISCUSSION

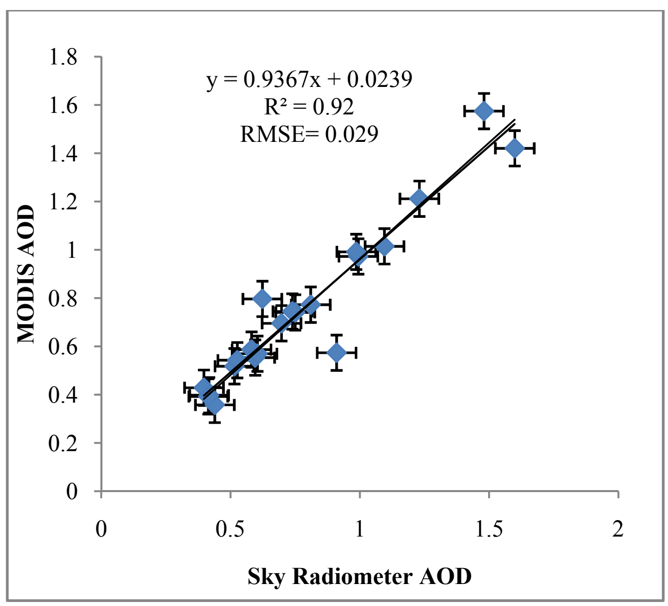


Fig. 2: Global comparisons of MODIS- and AERONET derived τ at 500nm wavelength, encompassing 21 points

from AERONET site located at Delhi. The solid line represent the slopes of linear regression τα(MODIS) = 0.9367(τα Sky Radiometer) ±0.0239.Temporal and spatial standard deviations are shown as the error bars in x(AERONET)- and y(MODIS)-direction respectively.

A total of 21 points representing Delhi AERONET sites meet our match-up criteria for the MODIS- and AERONET τα derived in the period of April-June. The scatter plots in Fig. 2 depict overall a very good agreement between MODIS and AERONET with Slope~ 0.93, Intercept~ .0239, and high correlation coefficients (R) ~ 0.95. Nearly all the points fall within the retrieval errors of τα = ±0.05 ± 0.2τα with RMS errors of 0.029.

Spectral Dependence of Aerosol Optical Depth

Angström exponent (α) is commonly used to describe the spectral dependence of τa. For MODIS, α is calculated as follows

$$\alpha = -In\,(\tau a^{0.47\,\mu m} / \tau a^{0.66\mu m}) / In(0.47/0.66)$$

where a0.47 µm and a0.66µm are the MODIS-derived a at 0.47µm and 0.66µm, respectively.The uncertainty in surface reflectance is shown to be one of the important factors in the derivation of α. A reasonable fit (Slpoe~0.97, Intercept~0.09, Corelation coefficient R~0.99) was found between MODIS- and AERONET-α. Other factors affecting the accuracy of α include the uncertainties of aerosol properties, e.g particle size [11].

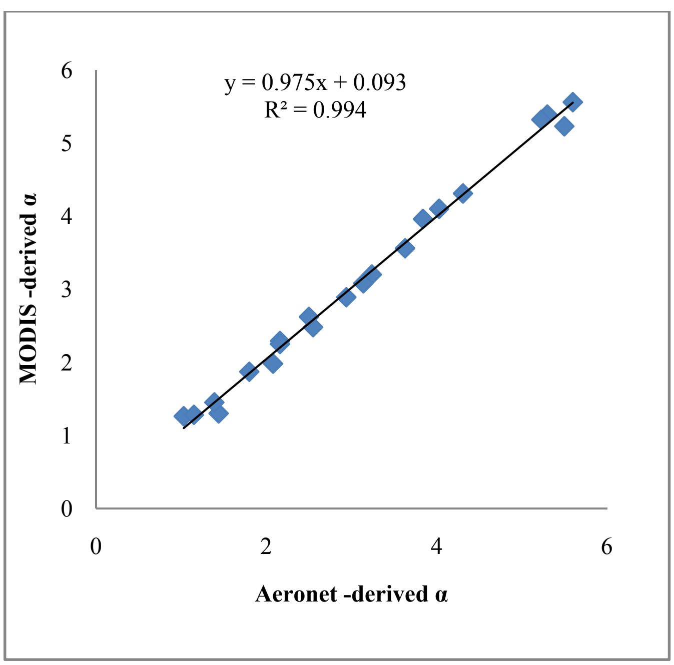
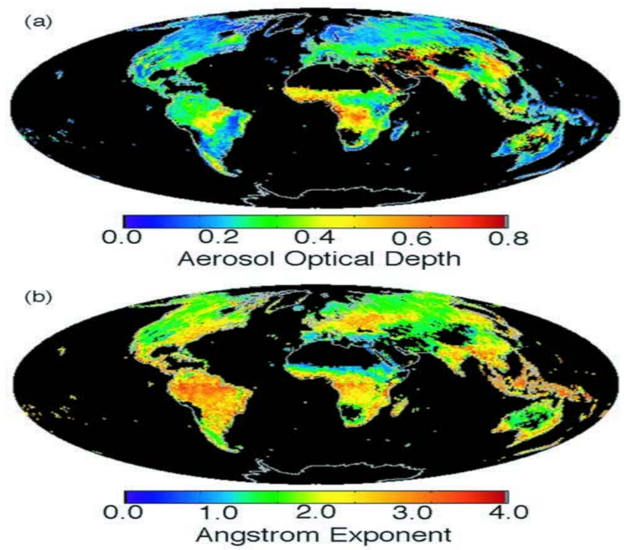


Fig. 3: Comparison of MODIS and AERONET-derived α

Aerosol Distribution Over Delhi

The monthly means of τa and α. are shown in Fig. s 4a and 4b for May 2011, respectively. We select the month of May because there are more complete data in that month than in April or June. Air pollution is most visible over delhiwith mean τa ~ 0.4–0.5. The corresponding a values reveal reasonable correlation with possible mixture of urban/industrial or biomass burning aerosols with dust particles.



Source: aqua.nasa.gov

Fig. 4: Global monthly mean of (a) τα (at 550nm) and (b) α derived from MODIS 1°×1° level-3 daily products of May 2011.

5. CONCLUSION

The MODIS aerosol retrievals over land meet our expectation with unprecedented accuracy. With the continuous refinements in instrument calibration, we expect the quality of MODIS aerosol products to be improved with time. However, several sources of the errors in aerosol retrieval remain to be solved, such as sub-pixel cloud, snow/ice, and water contamination, uncertainties in heterogeneous surface reflectance, and aerosol properties beyond the scope of the assumptions of Aerosol Models.

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